Factory Trials to Determine How Sugarcane Trash Impacts Downstream Processing Including Affinated Sugar Production

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ABSTRACT

In many countries including the United States and South Africa, certain areas are changing to green from burnt cane harvesting, due to public and environmental pressures against burning and the current interest in using sugarcane trash as biomass. Since the 1940s there have been world-wide factory trials on green cane processing but none have managed to shed light on the effect on downstream processing beyond clarification. This paper reports on the effects of processing green billeted and/or whole-stalk sugarcane compared to burnt billeted and/or whole-stalk sugarcane. Trials were conducted at two factories situated in the Midlands area of South Africa, which operate either a tandem mill or a diffuser. Sufficient cane of each treatment was harvested and processed at each mill to purge the extraction plant of other cane. Trash tissues, direct analysis of cane (DAC), and bagasse samples in the front end were collected and analyzed. A bulk sample of mixed juice was transported to the Sugar Milling Research Institute (SMRI) pilot plant to produce clarified juice, syrup, A-massecuites, A-molasses, A-sugar, and affinated sugar. Stalks contribute more to the load of colour delivered to the factory than the trash tissues because of their higher mass and volume. The increased trash levels caused an increase in the colours of affinated sugar of 25 IU (relating to 50 IU in VHP sugar) per 1% trash. The green leaves and growing part region trash tissues markedly affected the affinated sugar colour. Increased trash levels resulted in decreased DAC and mixed juice (MJ) purities in the factories with serious economic consequences. For every 1% increase in trash there was an approximate 0.41% decrease in MJ purity. An increase in trash, generally, increased the clarification settling rate but also increased mud volumes. The effect of trash on processing of the mixed juice in the pilot plant was a reduction in purity all the way through to A-massecuite.

INTRODUCTION

With increasing labor costs and reduced availability of agricultural labor in South Africa there has been a slow but marked shift to mechanized sugarcane harvesting and loading. This coincides with a progressive increase in green sugarcane harvesting due mainly to environmental pressures, particularly from the tourism industry. In 2008, ~15% of the sugarcane was harvested green and further increases in sugarcane trash are expected at South African factories. A similar trend to reduce burning is occurring world-wide, while industries like Australia, Columbia, Mauritius and Reunion have been practicing green sugarcane harvesting for many years. In addition, the recent acceleration in the development of new markets for sugarcane trash as biomass for, i.e., the produetion of energy and bio-products, has refocused the spotlight on green cane harvesting and the handling of trash (Purchase *et al*, 2008).

Researchers throughout the world (Arceneux and Davidson, 1944; Mayoral and Vargas, 1965; Scott *et al,* 1978; Foster, 1979; Lamusse and Munsamy, 1979; Reid and Lionnet, 1989; Purchase *et al* 1990; Lionnet and Reid, 1993; Bernhardt *et al*, 2000; Kent *et al,* 2003; Gomez *et al,* 2006) have generally reported that an increase in tops and trash entering a faetory (mill or diffuser) with the cane results in (i) reduced payloads per consignment due to the lower density of trash and tops causing increased transport costs and sometimes reduced payment, (ii) reduced crush rates and throughputs due to the larger volume of fiber associated with any given amount of sucrose (also resulting in a longer processing season), (iii) slippage on the mill rolls due to leaves, (iv) chokes in the knives and shredders due to high fiber load, (v) adjustments to mill settings and/or diffuser operation, (vi) lower extraction of suerose losses because of increased volume of bagasse, (vii) higher bagasse moisture content, (vii) lower mixed juiee purity due to increased levels of impurities, such as reducing sugars, ash and colourants, with associated effects on clarification, (vii) slightly reduced mixed juiee pH (higher lime demand) due to the presenee of organic aeids, (viii) evaporator fouling due to impurities, and (viii) lower molasses exhaustion. Smits and Blunt (1976) also reported that increased green trash would increase masseeuite viseosities, detrimentally effeeting crystallization processes, and causing more rapid blinding of centrifugal screens.

The quantity and quality of trash associated with field sugareane depends on many factors and particularly on the variety (Waguespack and Jaekson, 2006; Eggleston et al, 2009a). Bernhardt *et al* (2000) showed a signifieant reduction in throughput rates with green over burnt whole-stalk cane because (i) more effort is required to harvest green cane and growers cannot maintain the same harvesting rates with their existing cutting erews, and the rate of delivery is slowed down with the same crew and so the factory eompensates by redueing the fiber rate, and (ii) ehokes can occur with green cane. Reporting on a 4-day trial of processing green harvested cane it was shown that, although only approximately one third of the total eane delivered was eventually green, there was still a reduetion in harvest rate and supply rate, an inerease in choking tendencies, an increase in sugar colour and a decrease in boiling house recovery. Reid and Lionnet (1989) predicted that, with the presence of tops and trash, there would be marked inerease in the VHP (very high pol) sugar eolour and a significant reduction in sugar recoveries. With the increased world-wide production of VHP, VVHP (very, very high pol) and VLC (very low colour) real industrial eolour data, rather than predictions, on such sugars are urgently needed.

The use of sugarcane trash terms varies in the literature and these have often not been clearly defined. A complete definition of sugarcane trash should include brown, dried leaves (BL), green leaves (GL), and the growing point region (GPR). Not enough is known about the physico-chemical differences between these different types of trash tissues and stalk tissue and the effects of the different tissues on factory and refining processing. In particular, the differences in the processing effects of brown versus green trash have been mostly ignored (Eggleston *et al*, 2009a, b).

The traditional harvesting procedure in the South African sugar industry is burning of the BL from the stalk in the field followed by manual cutting and topping, and meehanical loading, resulting in the delivery of stalks free from GL and GPR with minimal associated BL attached. However, many variations on this theme are eurrently observed which includes not topping, green cane harvesting (manual and mechanical), and meehanieal (combine) harvesting. Some factories in South Africa and other parts of the world even encourage the delivery of increased non-stalk material to increase boiler fcedstock (bagasse) without realizing the dctrimental effect this has on processing opcrations (Reid and Lionnet, 1989).

This project investigated the effeet of green cane harvesting on upstream and downstream factory processing including affinated sugar quality, which is something that has been attempted but never quite realized. Enough harvested cane of the same variety and age was crushed to purge and refill the front end of the factory being studied. No attempt was made to manipulate the harvesting practices or the resulting trash levels. Mixed juice (MJ) was collected after the factory MJ scales and then further processed in a pilot plant at the Sugar Milling Researeh Institute (SMRI) into A-sugar and affinated sugar. Two factories were used, namely Noodsberg (NB) and UCL Company Limited (UCL) which are situated in the KwaZulu-Natal Midlands adjacent to one another (within 10 km). NB operates a milling tandem while UCL has a diffuser which makes for an additional and quite novel comparison. Every effort was made to minimize deterioration to study trash effeets alone. The main objective was to estimate the effects of the increased trash levels on downstream processing at the factory and on refinery affinated sugar, with emphasis on the different types of trash that was delivered.

EXPERIMENTAL

Direct Measure of Trash and Stalk Components of Field Sugarcane

Approximately twenty-five randomly chosen band-cut whole-stalks of variety N12, with green and brown leaves still attached, were obtained from one of the three fields used for the NB and UCL factory trials. The sample was separated into the following components: brown, dried leaves (BL); green leaves (GL); the growing point region (GPR) which is the immature apical internodes above a natural breaking point in the stalk; and the remaining stalk (S) composed of hardened nodes and internodes. Eaeh tissue type was weighed and the percent trash on a wet mass basis caleulated. Randomly chosen samples of the separated tissues were transported to SMRI and shredded by passing through a Jeffco cutter grinder (Jeffress Engineering Pty Ltd, Australia). Shredded tissue was then mixed with water and processed in a cold digestor to obtain an extract for analyses of suerose, fructose and glucose by GC (SASTA Method 1.9 [2005]) and solution colour according to ICUMSA Method GS1/3-7 (2003) at pH 7.0. Moistures of shredded portions of eaeh tissue type were determined after drying in an oven at 105°C for 1 h, and used for calculations of tissue mass pereentage on a dry basis.

Direct Measure of Trash in Harvested Sugarcane at the Factory

Four random grab samples (~16 kg) were obtained from the factory piles of green or burnt billeted cane. For burnt whole-stalk eane two random grab samples (~12 kg) of ~16 stalks were obtained from the factory pile. Each sample was separated into BL, GL, GPR and S. If roots were present these were associated with the S. Leaves with any green color were designated GL. Eaeh tissue type was weighed and the percent trash on a wet and dry mass basis caleulated. For burnt whole-stalk, typically only BL was associated with the stalk, either attached or unattached. The unattached trash blew away easily so only a low estimate was obtained. The separated tissues were then bagged and transported to the SMRI in Durban. The tissues were treated as described for field sugarcane above.

Factory operation during the trials

Noodsberg (NB) Trial: Comparison of green and burnt billets, and burnt whole-stalk cane

Cane preparation equipment at the NB factory consisted of a leveller and a whole-stalk shredder. Due to the higher density of billets, the conveyer belt speed was adjusted as a matter of routine when billets are being crushed. The factory operated a 5-mill tandem plus one drying mill with a fiber residence time of ~6.5 min. In the morning before the first trial concluded (green billeted cane), the factory experienced a number of chokes in the second mill right under the Donnelly chute. The same problem, but to a lesser extent, was experienced on the second day (burnt billeted cane) but not on the last day (burnt whole-stalk). For each of the three trials at NB, the factory biocide dosage for the morning shift was discontinued before and during the trial.

UCL Trial: Comparison of green and burnt billets

Cane preparation equipment at the UCL factory consisted of a leveller, a set of knives and a shredder. As was done with the NB trial, the conveyer belt speed was adjusted to compensate for the higher density of the billets. The factory operated a 60 m long Bosch™ chainless cane diffuser controlled under normal conditions at 1 m/min. For each of the two trials at UCL, the factory biocide dosage for the morning shift was discontinued before and during the trial.

Factory Analyses and Sampling

Direct Analysis of Cane (DAC)

The South African sugar industry uses the direct analysis of cane or DAC method to determine the quality parameters of the cane. The analyzed parameters are pol, Brix, purity, fiber (calculated) and moisture (SASTA Methods 1.1 - 1.5 [2005]). Cane samples were taken after preparation (knives and shredding) but before extraction (diffusion or milling) on a continual basis for nominated consignments only, and are representative of a specific cane consignment through an automated tracking system. The results are normally used for cane payment purposes.

Harvesting

NB Factory

A three day trial was conducted at NB factory from 18-20 June 2008. One grower supplied the cane for the billet trials (days 1 and 2) from a single field in the Midlands area of South Africa and another grower supplied the burnt whole-stalk cane on day 3. All the cane was N12 variety and 20-24 months of age. Approximately 150 tonnes of cane were supplied for each trial date. The first trial, green billets, was conducted on 18 June under slightly wet environmental conditions. The field cane was combine-harvested (Claas™ CC 3000; ground speed 4 km/h and blower and fan speeds 1624 and 1398 rpm, respectively) between 7:00 and 10:30 am and immediately delivered to the factory and processed. For the second trial, burnt billets, the field cane was first burned in the field, under slightly wet conditions, in the early evening of 18 June. It was then combine harvested (ground speed 7 km/h and blower and fan speeds 1624 and 1398 rpm, respectively) between 8:00 and 11:00am on 19 June and immediately delivered to the factory and processed. For the third trial, burnt whole-stalks, the field cane was first burned in the field in the early evening of 19 June. Hand-cutting began soon afterwards and all the cane was delivered to the factory by 10:00 am the following morning (20 June).

UCL Factory

A two day trial was conducted at UCL factory from 25-26 June 2008 under the same conditions as the NB trials above. Cane was cut from a different field on the same farm that was used in the NB factory billet-trial. As in the NB billet trial, all cane was N12 variety and 20 months age. Billet trials were conducted on days 1 and 2. Approximately 250 tonnes of cane were supplied for each trial date. The first trial, green billets, was conducted on 25 June under cold and dry conditions. For the second trial, burnt billets, the field cane was first burned in the field in the early morning of 26 June, combine harvested between 8:00 and 11:00 am and immediately delivered to the factory.

Crushing and Extraction

Every effort was made to minimize cut-to-crush delays and, therefore, deterioration to evaluate the effects of trash alone.

NB Factory

Each trial at NB lasted 1 h to ensure that the previous juice in the tandem mill (crush rate ~275 tonnes/h) was purged and that the bagasse (from the last mill) and MJ samples collected were representative of the trashy cane supplied. DAC samples (~8) were collected across the h and analysed by the factory laboratory.

UCL Factory

Each trial at UCL lasted 2 h to ensure the previous juice from the chainless diffuser (crush rate ~135 tonnes/h) was purged and that the bagasse and MJ samples collected were representative of the trashy cane supplied. DAC samples (at least 9) were collected across the 2 h period and analyzed by the factory laboratory.

Mixed Juice (MJ) Collection

Towards the end of each trial, twelve 25 L containers each containing two drops of mercuric chloride preservative, were filled with MJ and transported immediately to SMRI in Durban for sub-sampling (for analysis) and processing of the bulk into clarified juice.

Pilot Plant Processing

The SMRI pilot plant facility (Lionnet and Reid, 1993) was used to produce clarified juice (CJ), final evaporator syrup (FES), A-massecuite, A-molasses, A-sugar and affinated sugar from the mixed juice collected at the factories. A hot lime clarification method was followed and clarification took place in a 150 L clarifier tank. The juice, with or without phosphoric acid as required (50 ppm), was heated to a light boil with steam, limed to pH 7.2 (95 °C) with milk of lime (MOL; 10%) and then boiled again. Polyanionic flocculant (same as factory: LT027; 0.1%) was added at a dosage of 3 mg/kg juice and the mud allowed to settle for 30 min before CJ was decanted. The CJ was immediately placed in the evaporator feed drum (300 L) and fed from the drum into the plate-type evaporator (Alfa-Laval; 6 m^2 heat transfer area). The evaporator was operated at a steam pressure of between 10 and 20 kPa (g) and the vapour pressure was maintained at -10 kPa (g). The typical evaporation rate varied from 0.8 to 1.2 kg/min. The evaporator was operated on a eontinuous reeyele system and the FES produeed was removed at 65-68 Brix. The FES was then boiled in a pilot vaeuum pan at approximately 65 °C and a pressure of -90 kPa(g). The syrup was concentrated to approximately 70 Brix then seeded with a small amount of slurry (ground refined sugar erystals in methylated spirits, SASTA Lab Manual, 1985, pp 160-162), and crystals were allowed to grow. The resulting masseeuite was separated into A-sugar and A-molasses in a laboratory centrifugc without adding wash water and without control of temperature or elapsed time.

Production of Affinated Sugar

SASTA method 7.3 (2005) was followed to produce affinated sugars. Some of the A-sugar produced was mingled with a saturated refined sugar solution and centrifuged again. The remaining sugar was allowed to air dry. This washed sugar (200 g) was then mixed with a further saturated refined sugar solution (400 g) for 15 min and then filtered under vaeuum through a sinter glass (coarse) funnel. This mix was further rinsed and filtered with (1) saturated refined sugar solution (200 g), (2) 95% methanol saturated with refined sugar solution (400 em^3), and (3) 100% methanol saturated with refined sugar (200 em^3). The final produeed affinated sugar was then left to air dry.

Laboratory Hot Lime Clarification Settling

MJ (1 L) in a eovered stainless steel eontainer with a heating element was heated to boiling with constant magnetie stirring. If phosphate was required 50 ppm of phosphorie aeid (25% aeid strength) was added to the MJ before heating. Milk of lime (MOL; 10%) was then added with stirring until the juiee pH reached 7.2 (95°C). The heated, limed juiee was then brought to a seeond boil for 1 min to remove interfering bubbles, and flocculant solution (LT027; 0.1%) was added at 3 ppm using a pipette. The juice was immediately poured into a settling tube (3.5 × 31 cm) in a glass water bath (96°C) to a volume of 250 cm^3 and stoppered. Mud level readings were taken between 0 and 18 min, and also after 30 min of settling. The tube was then removed and the eontents cooled to room temperature (~25°C). Brix and pH of the elear juice (CJ) were noted. Settling and mud volume (MV) measurements and ealeulations wcre based on the methods of Sehmidt (1953) and Lionnet and Ravnö (1976) with modifications. Mud volume (cm^3) was plotted against time (min). Break point (sec) was the time it took for the mud to settle to half its original volume. The mud volume after 18 (MV_{18}) and 30 min (MV_{30}) were read directly and cxpressed as volume pereentage.

Sample Analyses

Sample Colour

Colour was measured as the absorbance at 420 nm and calculated according to ICUMSA Method GS1/3-7 (2003) at pH 7.0.

Oscillatory Deformation Rheometry (ODR)

Mechanieal spectra of syrup, molasses, and massecuite samples were recorded on a AR1000 Advanced [Oscillatory Deformation] Rheometer (TA Instruments, USA) using eone and plate geometry of angle 2° and diameter 4.0 cm. Sample temperature was 20°C controlled to within ± 0.01°C by a peltier cell. Readings were taken 1 min after the sample had attained thermal equilibrium. A frequency sweep of 0.1 to 1000 rad/sec was applied to each sample.

Conductivity Ash

This was determined according to ICUMSA Method GS1/3/4/7/8/-13 (1994).

Sucrose, Fructose and Glucose

These sugars were measured using gas chromatography (GC) according to SASTA Method 1.9 (2005).

Statistical Analyses

Analyses were undertaken using Microsoft Office Excel (2003).

RESULTS AND DISCUSSION

Trash Levels

The total trash levels for the field N12 variety cane used at NB and UCL were 30% (m/m) comprising of 7-9% BL, 12-14% GL and ~8.5% GPR (Table 1 and Fig. 1). When billeted cane is harvested, the amount of trash delivered to the factory is always lower than the field cane trash because the extractor fans on the combine harvester blows off some trash in the field. The amount removed in the field depends on the fan and ground speeds of the combine harvester, as well as the setting of the combine cutter.

Table 1: Trash levels of cane from NB and UCL trials on a tissue wet mass basis (%)

Trash type	Field Cane*	NB 1 Green billets†	NB 2 Burnt billets†	NB 3 Burnt whole-stalk†	UCL 1 Green billets†	UCL 2 Burnt billets†
Stalk	70.0	82.7a‡	88.7b	98.3	88.5a	89.2a
BL	9.4	5.2a	3.1b	1.4	4.6a	1.9b
GL	11.8	3.9a	2.9a	0.3	2.4a	3.9a
GPR	8.8	8.3a	5.3b	0.0	4.5a	5.0a
Total Trash (BL+GL+GPR)	**30.0**	**17.4a**	**11.3b**	**1.7**	**11.5a**	**10.8a**
GL/BL ratio	**1.6**	**0.8a**	**0.9a**	**n/a[b]**	**0.5a**	**2.1b**

* *Average of 2 replications*

† *Average of 4 replications*

‡ *The same lower case letters represent no statistical differences (P<0.05) among the billeted cane types for an individual tissue and factory only*

[b] *n/a = not applicable*

For the NB trial (Table 1), the green billets delivered on day 1 of the trial contained a total of 17.4% trash (Fig. 2) and the burnt billets on day 2 contained a total of 11.3% trash (Fig. 3). In comparison, the burnt whole-stalks delivered on day 3 of the trial comprised of only attached and associated BL of less than 2% of the sample (Fig. 4). (Visually, ~2-5% BL was associated with the burnt whole-stalks; sampling was difficult.) *Therefore, there is no such thing as a clean, burnt cane stalk delivered to factories for processing.*

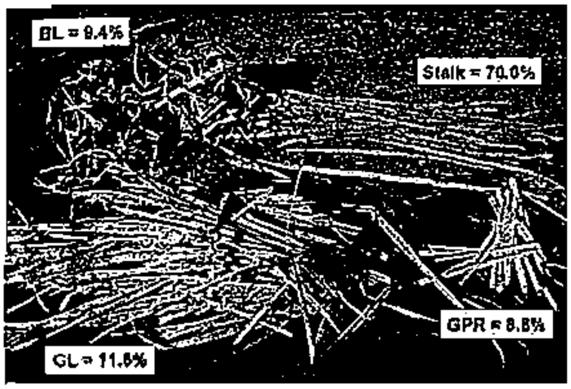

Fig. 1. UCL & NB N12 field cane

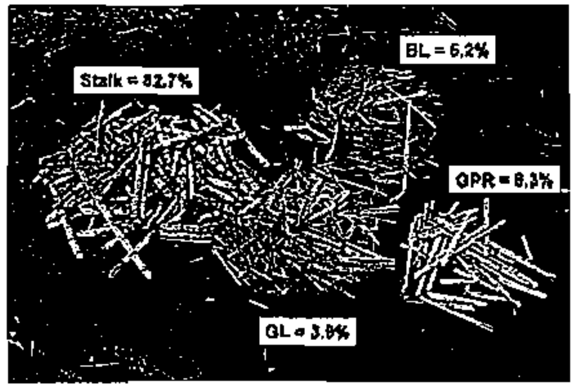

Fig. 2. NB N12 green billets

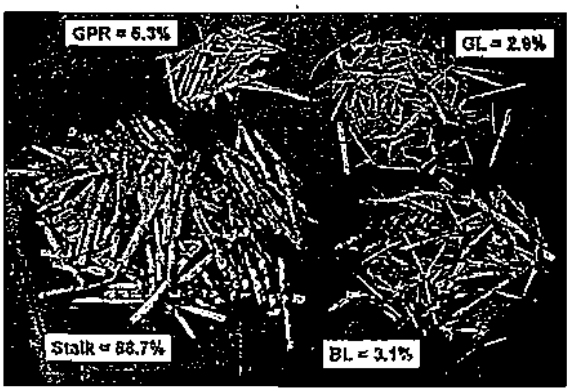

Fig. 3. NB N12 burnt billets

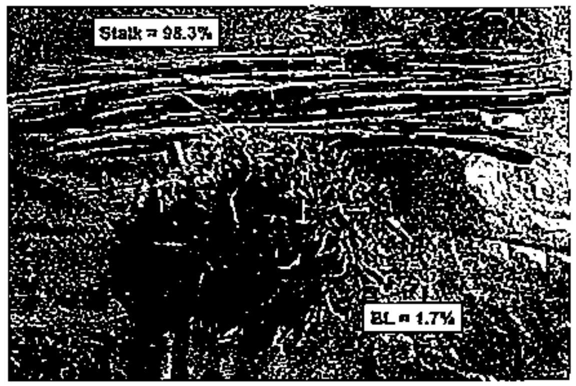

Fig. 4. NB N12 burnt whole-stalks

At UCL the green billets trial on day 1 contained 11.5% total trash (Fig. 5) and the burnt billets on trial day 2 contained 10.8% total trash (Fig. 6). There was no significant difference in total trash between the green billet and burnt billet trials. The two trials at the UCL factory were more likely similar than those at the NB trial (Table 1) because of the drier conditions during the UCL trial. The wetter conditions for the NB trial (particularly during the first 2 days) likely exaggerated the significant differences in trash levels between the green and burnt billets. Overall, it is important to note that the NB trial showed marked significant differences for individual and total trash levels between the green and burnt billets while the UCL trial showed significant differences only for BL (Table 1). Furthermore, the GL/BL ratios between the green and burnt billets were 0.8 and 0.9, respectively, at NB while significantly different ratios of 0.5 and 2.1, respectively were observed at UCL (Table 1), the effects of which will be explored later in the report.

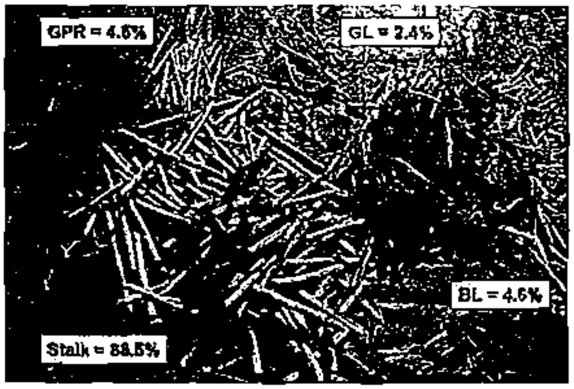

Fig. 5. UCL N12 green billets

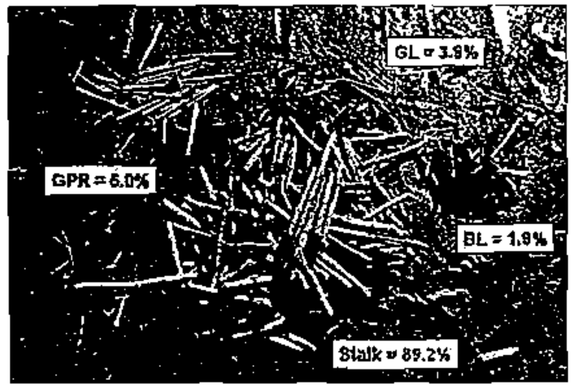

Fig. 6. UCL N12 burnt billet

The main sugars (sucrose, fructose and glucose) and colour at pH 7.0 of the UCL tissue extracts, quoted on a sample Brix basis, are listed in Table 2. On a sample Brix basis the GL had the highest colour, followed by BL, GPR and the stalks with the lowest colour (Table 2).

Table 2: Sucrose, fructose, glucose and colour quoted on a sample Brix[a] basis of UCL sugarcane tissues

Type	Tissue	Fructose (%)	Glucose (%)	Sucrose (%)	ICUMSA Colour (IU)
Field cane	Green leaves	0.17	0.14	0.09	189,400
	Brown leaves	0.00	0.00	0.01	165,000[b]
	GPR	0.24	0.21	0.42	123,430
	Stalk	0.06	0.06	4.85	11,830
Green billets	Green leaves	0.17	0.12	0.44	178,530
	Brown leaves	0.11	0.09	0.32	161,120
	GPR	0.31	0.25	0.85	132,250
	Stalk	0.06	0.04	5.60	13,720
Burnt billets	Green leaves	0.15	0.10	1.49	174,350
	Brown leaves	0.06	0.05	1.04	105,520
	GPR	0.20	0.15	1.57	70,320
	Stalk	0.04	0.03	6.05	16,730

[a] *Brix of the diluted, extracted sample*
[b] *Estimated value*

In contrast, when colour was further calculated on a % tissue wet mass basis, which better reflects the actual load of colour deliverable to the factory (Table 3), the colour loads by the different tissues were much different. In particular, the stalk contributes much more to colour at the factory than either GL or BL, just because of the much greater mass and volume of stalks. *Therefore, the contribution of stalks to delivery of colour at the factory should not be underestimated.* This approach also clearly showed the larger contribution of reducing sugars by the GPR and stalk than previously considered.

Table 3: Sucrose, fructose, glucose (by GC) and colour loads[a] of trash at UCL quoted on a % tissue mass basis

Type	Product	% on tissue wet mass basis			
		Fructose	Glucose	Sucrose	Colour load[a]
Field cane	Green leaves	0.02	0.02	0.01	22,260
	Brown leaves	0.00	0.00	0.00	15,540
	GPR	0.02	0.02	0.04	10,860
	Stalk	0.04	0.04	3.40	8,280
Green billets	Green leaves	0.00	0.00	0.01	4,230
	Brown leaves	0.01	0.00	0.02	7,400
	GPR	0.01	0.01	0.04	6,000
	Stalk	0.03	0.04	5.00	12,140
Burnt billets	Green leaves	0.01	0.00	0.06	6,840
	Brown leaves	0.00	0.00	0.05	1,950
	GPR	0.01	0.01	0.08	3,640
	Stalk	0.04	0.03	5.40	14,930

[a] *Colour load = ICUMSA colour × wet mass*

Direct analysis of cane (DAC)

NB Trial: Comparison of Green and Burnt Billets, and Burnt Whole-Stalk Cane

Results from the analyses of different DAC samples collected continually over the three trials at NB are listed in Table 4.

Table 4: Average NB DAC results for green and burnt billets and burnt whole-stalk cane

Trial cane (N)	Quantifier	Pol (%)	Brix (%)	Purity (%)	Fibre (%)	Moisture (%)
Green billeted (15)	Average	13.36	15.20	87.84	14.28	70.52
	SD	0.49	0.36	1.36	0.69	0.50
	RSD (%)	3.67	2.34	1.54	4.85	0.70
Burnt billeted (15)	Average	13.66	15.42	88.58	14.37	70.21
	SD	0.27	0.22	0.79	0.74	0.73
	RSD (%)	1.96	1.40	0.89	5.13	1.04
Burnt whole-stalk (8)	Average	15.91	17.27	92.12	15.76	66.97
	SD	0.10	0.14	0.33	1.68	1.62
	RSD (%)	0.66	0.83	0.35	10.66	2.42
F-tests	P1 (0.05)	0.04	0.05	0.08	0.74	0.18
	P2 (0.05)	0.00	0.00	0.00	0.01	0.00
	P3 (0.05)	0.00	0.00	0.00	0.01	0.00

N ≡ number of samples; SD ≡ standard deviation; RSD ≡ relative standard deviation

P1 ≡ probability that values for the green and burnt billets differ significantly

P2 ≡ probability that values for the green billet and burnt whole-stalk differ significantly

P3 ≡ probability that values for the burnt billet and whole-stalk differ significantly

(P<0.05 indicates a significant difference at the 5% level)

There was a significant difference for pol and Brix values between the green and burnt billet NB trials (Table 4), with the values for burnt billets being higher, as expected, due to lower trash levels. The purity values calculated from the same pol and Brix values were not significantly different, indicating that the ratio between pol and non-pol in the samples remained similar. However, this may also be due to the smaller relative standard deviation associated with the purity calculation. Fiber and moisture levels between the billet trials were not significantly different (Table 4).

In comparison to the similar results from the two billet trials, there were significant differences between whole-stalk cane and billets for all the measured parameters (Table 4). The DAC moisture of the burnt whole-stalk was significantly lower than for both billets (Table 4). The lower moisture of the burnt whole-stalks most likely is because they contain considerably less moisture-retaining trash components (Table 1). This may also explain the higher fiber values in the burnt whole-stalk. Another explanation may be that, since the fiber values are calculated as a function of the moisture and Brix (of the extract) values, the two inconsistencies could have a single cause. Note that the total trash levels between the NB green (17.4%) and burnt (11.3%) billets differed markedly, while the GL/BL ratios were of the same order (0.8-0.9) (Table 1).

UCL Trial: Comparison of Green and Burnt Billets

Results from the analyses of different DAC samples taken continually over the two trials are listed in Table 5.

Table 5: Average UCL DAC results for green and burnt billeted cane

Trial cane (N)	Quantifier	Pol (%)	Brix (%)	Purity (%)	Fibre (%)	Moisture (%)
Green billets (15)	Average	13.88	15.32	90.56	16.50	68.18
	SD	0.38	0.33	0.78	1.86	1.82
	RSD (%)	2.74	2.14	0.86	11.24	2.66
Burnt billets (9)	Average	14.28	15.72	90.82	14.49	69.79
	SD	0.27	0.29	0.86	0.37	0.50
	RSD (%)	1.91	1.82	0.95	2.56	0.72
F-test	P (0.05)	0.02	0.01	0.51	0.01	0.02

N ≡ number of samples; SD ≡ standard deviation; RSD ≡ relative standard deviation
P ≡ probability that values for the green and burnt billets differ significantly
(P<0.05 indicates a significant difference at the 5% level)

For the UCL trial, pol, Brix, moisture, and fiber values were significantly different between the green and burnt billets (Table 5), while the purities of the samples did not differ significantly. As indicated earlier (Table 1), the GL to BL ratios between the green and burnt billets at UCL were 0.5 and 2.4 even though the total trash was around 11.5-11.8% (GPR levels were similar). This suggests that the types of trash (specifically GL or BL) rather than total trash amount had a significant effect on the pol, Brix and purity values at UCL.

Combined NB and UCL DAC Results

The NB and UCL total trash levels for each DAC sample were compared to the pol, Brix and purity values to define relationships, and are illustrated in Fig. 7. The DAC pol and Brix values were strongly correlated with total % trash levels while the purity correlations were only moderately correlated (Fig. 7). In addition to causing lower pol amounts, the trash also increased the non-pol impurities as indicated by the decreased purities. The Brix values decreased dramatically with increased trash levels. The method for DAC cold digestion uses exactly the same mass of water for each sample of cane. This shows the effect of the lower Brix levels in the brown and green leaves compared to the stalks.

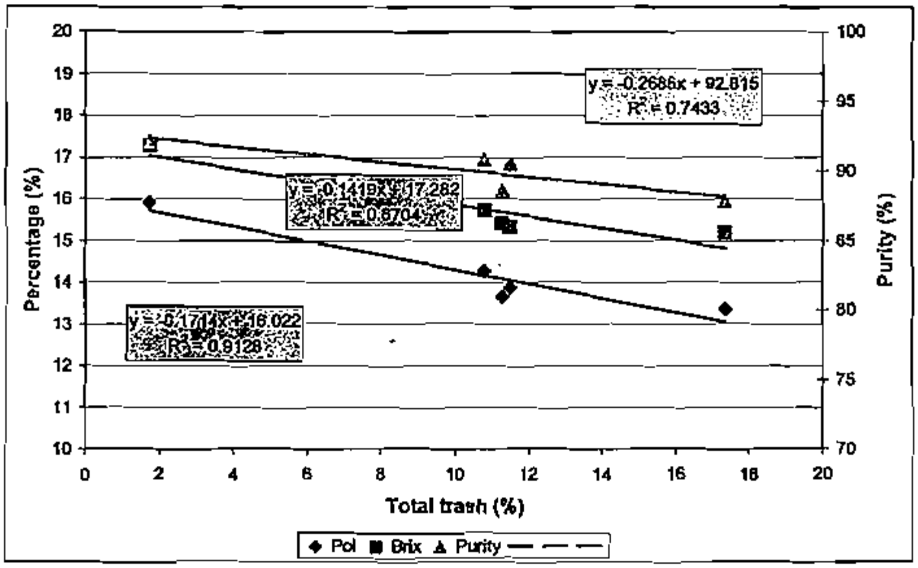

Fig. 7. The effect of total trash on pol, Brix and purity of DAC samples

Mixed Juice from the Two Factories

Sinee the MJ samples were obtained from the factories it allowed for a direct eomparison of the physico-chemieal properties of the MJs from the different trials (Table 6). The Brix levels in MJ are generally determined by operational faetory settings (sueh as the imbibition water to eane ratio) and *not* by the eane quality or type. Comparisons can, therefore, only be made on results expressed on a Brix basis. Results were compared to the total trasb levels to assess the effect of trash on the MJ quality. Note that the highest and lowest (as well as one of the three intermediate) trash levels were obtained at NB factory (Tables 1 and 6).

Table 6: Total trash levels and mixed juice (MJ) analytical results

Factory:	NB			UCL	
Cane Type:	Burnt whole-stalk	Burnt billets	Green billets	Burnt billets	Green billets
Total Trash (%)	*1.74*	*11.28*	*17.35*	*10.81*	*11.50*
MJ Pol (%)	15.46	11.40	11.68	11.51	11.26
MJ Brix (%)	16.80	13.02	13.66	12.83	12.54
MJ Purity (%)	92.02	87.56	85.51	89.71	89.79
MJ Sucrose (%)	15.43	11.50	11.69	11.58	11.31
MJ Fructose (%)	0.19	0.27	0.35	0.16	0.17
MJ Glucose (%)	0.20	0.25	0.38	0.12	0.13
MJ Colour (IU)	14,534	19,861	20,267	23,205	19,099
MJ Conductivity Ash (%)	0.45	0.44	0.45	0.43	0.42

Fig. 8 illustrates the effect of total % trash levels on the MJ apparent purity (based on pol) and true purity (based on GC sucrose) for both factories. A difference of more than 6.5% units was observed due to an increase in trash from 1.7 to 17.4% (Δ=15.7%). Therefore, for every 1% increase in trash there was an approximate 0.4% decrease in MJ purity. Furthermore, the 17.4% trash level is not that unusual for total trash levels delivered to South African factories. At another factory near the coast (Maidstone), 25% trash levels were measured in some delivery loads. This is the first time that actual trash levels delivered to a factory have been related directly to mixed juice parameters.

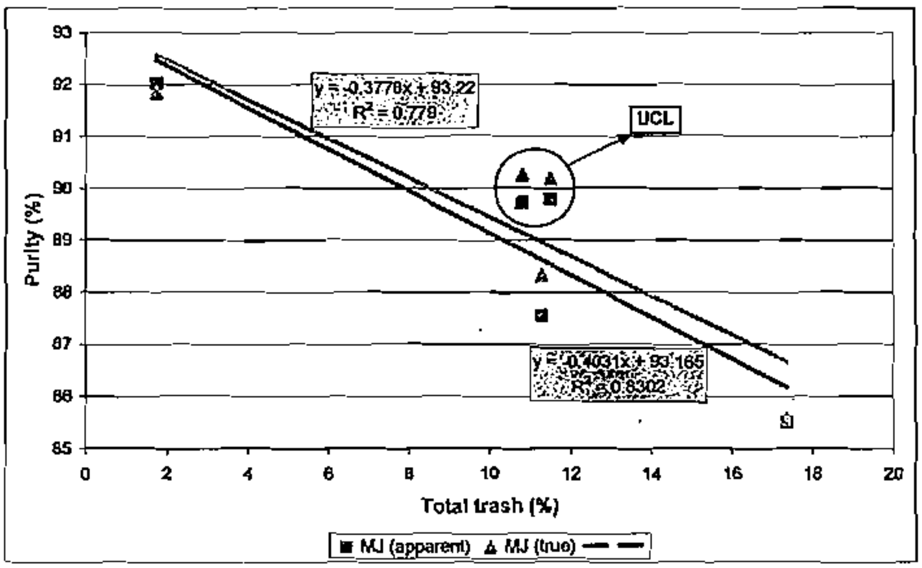

Fig. 8. MJ purities *versus* total trash levels

Mixed Juice Reducing Sugar and Colour Comparisons

Correlations between the MJ reducing sugars (fructose and glucose) and the trash levels were not as strong when combining data from the two factories (Fig. 9). However, a quantitative difference in fructose and glucose was discernable between the two factories, indicative of the differences in the extraction rates of the reducing sugars between the milling tandem at NB and the diffuser at UCL. Another possible explanation could be differences in enzymatic inversion rates between the factories. When each factory was evaluated separately the correlations coefficient (R^2) values were > 0.990 (not shown). As expeeted, there were much lower levels of reducing sugars and ash in the diffuser faetory MJs than in the milling tandem factory MJs (Rein, 1995).

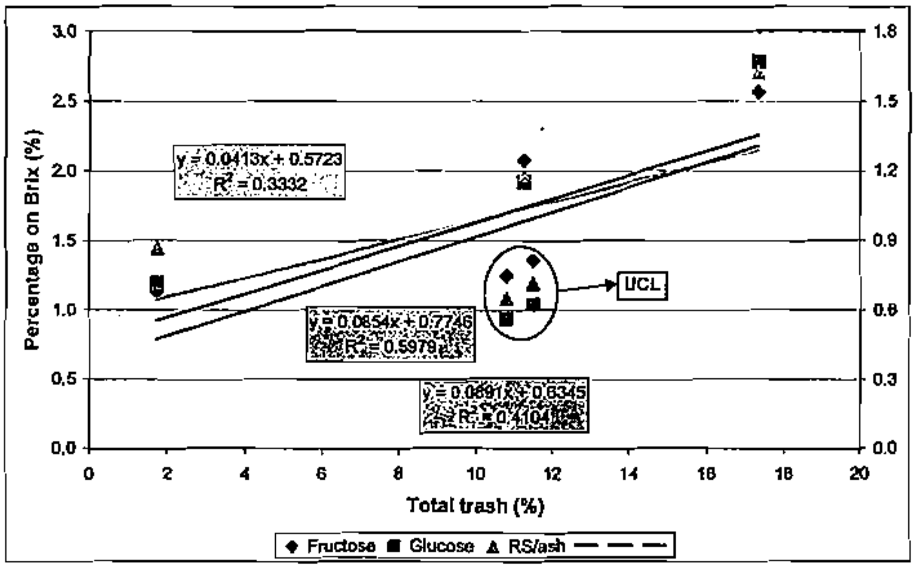

Fig. 9. Fructose, glucose and reducing sugars/ash ratio *versus* trash levels in mixed juice at NB and UCL

Nevertheless, increased trash levels typically caused an increase in the reducing sugars levels in the MJ. This was expected since the GL and GPR contribute significantly to the reducing sugars in the cane (Table 2). Although the conductivity ash values did not show correlations to the total trash levels, the reducing sugar to ash ratios were correlated with the total trash levels similarly to fructose and glucose.

Comparisons of the MJ colour contents with the total trash levels (Fig. 10) indicated moderate polynomial correlations; however, the linear correlation was strong (R^2=0.89) when just NB data was compared. The lower correlation from the combined faetory data is most likely because of the different faetory extraetion processes, *i.e.*, diffusion (UCL) versus milling (NB). Diffusion removes more eolour from trash than tandem mills (Rein, 1995). These results confirm previous reports that, generally, increased trash levels cause an increase the juice eolour at the faetory (Scott *et al*, 1978; Rein, 2005; Kent, 2007). In strong contrast to the colour results, when MJ eonductivity ash levels were related to total % trash levels, no significant relationship was found (Fig. 10).

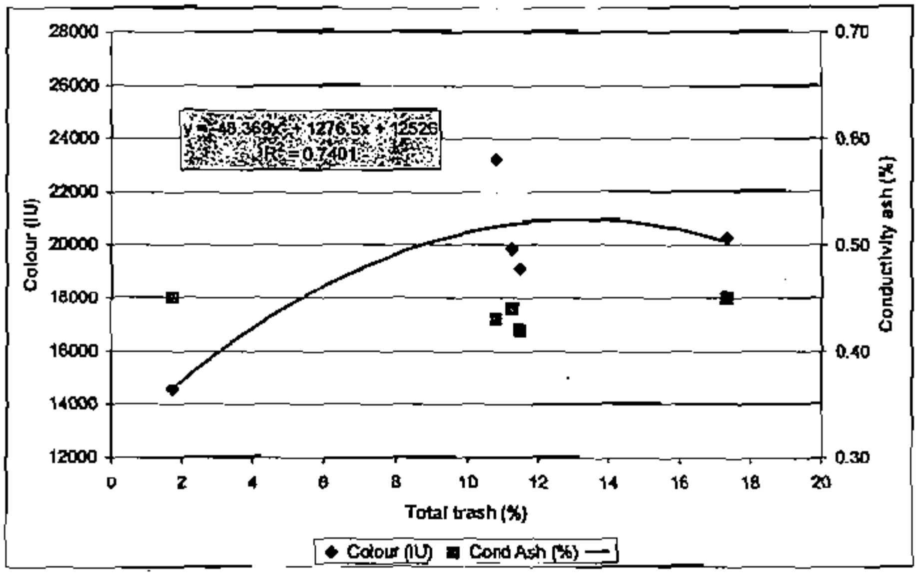

Fig. 10. Colour and conductivity ash in mixed juice *versus* total trash levels

Mixed Juice Laboratory Settling Tests

Settling and mud volume results for the NB samples are listed in Table 7. Excellent correlations (R^2=0.90 and R^2=0.93) were observed between total trash levels and the mud volumes expressed per unit mixed juiee Brix after 18 and 30 min settling (Muir *et al*, 2009). Thus, increased trash eaused a marked increase in the mud volumes per unit MJ Brix. Furthermore, a 1% inerease in trash caused a corresponding 0.0125% increase in mud volume % per unit MJ Brix after 30 min settling (laboratory scale equipment gives an indication only). Moreover, initial Brix of the MJ was not responsible for actual mud volumes (Table 7) which is in agreement with results recently reported on the clarification of juices obtained from trash and stalk eane tissues (Eggleston *et al*, 2009b).

Settling performances of the MJ were measured as the breakpoint (BP) and initial settling rate (ISR) (Table 7). As expeeted, there was an exeellent eorrelation (R^2=0.97) between the BP and ISR. Increased initial Brix of the juice had a mild effect on inereasing the breakpoint and, therefore, reducing the settling rate. However, the total trash levels had a much more dramatic effeet on the settling rate. There were excellent relationships between total trash and ISR (R^2=0.99) and BP (R^2=0.94). Overall, the higher the trash amount the faster was the settling rate but the higher the mud volumes per unit MJ Brix were. Eggleston *et al* (2009b) recently reported that the growing point region (GPR) was critical to sugarcane juice clarification. The increase in GPR in the total trash was, therefore, most likely responsible for faster settling rates. However, the trash was detrimental to the mud consistency and may be detrimental to the turbidity and colour of the clear juice (CJ). This warrants further investigation.

The main differences observed in the laboratory scalc clarification tests between the mill juice from NB and diffuser juiee from UCL were in the settling rates and mud volumes. The mill juices settled gradually (typical breakpoints of 20 sec were observed) whereas the diffuser juices had typically low mud volumes but settled too quickly and with no clear settling line to determine a breakpoint (Koster, 1995; Rein, 1995).

Overall, the muds from trashy green and burnt cane contained pieces of fiber and cellulosic material as well as large dark flocs (Muir *et al*, 2009) whereas the mud particles from the burnt whole-stalk were much smaller and uniform, indicating consistently well-formed flocs (Muir *et al*, 2009).

Table 7: NB laboratory clarification results

Cane Type	Burnt Whole-Stalk	Burnt Billets	Green Billets
Total Trash (%)	*1.7*	*11.3*	*17.3*
MJ Brix (°Bx)	17.0	12.8	13.7
MV_{18} (%)	18.4	14.7	17.6
MV_{30} (%)	17.5	14.3	17.2
CJ Brix (°Bx)	17.3	13.2	13.9
MV_{18}/Bx (% per unit MJ Bx)	1.08	1.15	1.28
MV_{30}/Bx (% per unit MJ Bx)	1.03	1.12	1.26
Breakpoint (sec)	48.0	21.0	16.1
Initial settling rate (ml/min)	168.5	376.3	470.5

Pilot Plant Processing of Mixed Juice into A-Sugar

The MJs from each trial were processed in the SMRI pilot plant and samples of clear juice, evaporator syrup (FES), A-massecuite, A-molasses, and A-sugar were analyzed for a range of physico-chemical properties. Note that the average particle size of the A-sugar was typically less than 100 μm and that this sugar, therefore, does not resemble A-sugar from a factory. Nonetheless, trends are informative.

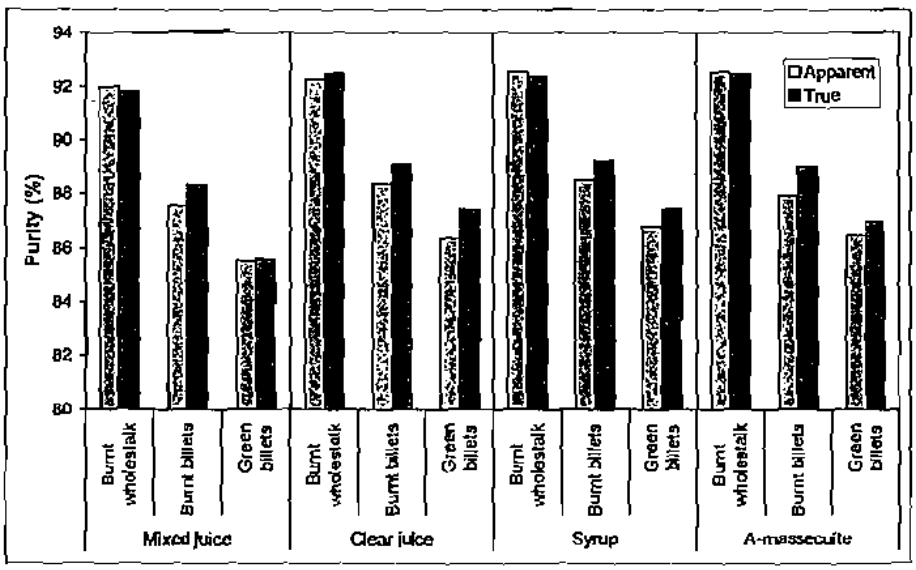

Fig. 11. Purity levels in NB pilot plant samples

Fig. 11 shows the apparent (based on pol) and true (based on sucrose) purity values for the pilot plant samples of the three different types of cane from the NB trials. Both purity values show a clear subsequential ("knock-on") effect across factory processing, following the order, from worst to best, of green billets < burnt billet < burnt whole-stalks all the way to the massecuites. Molasses purities (not shown) also followed the subsequential effect. This is the first time that an unequivocal effect due to the trash levels has been shown on downstream processing using a pilot plant. To have demonstrated this effect across a factory would have been practically impossible as at least 3-day loads of cane would be needed.

The apparent and true purity values for the UCL samples (Fig. 12) did not differ much due to the similar trash levels delivered with the green and burnt billeted cane at UCL (Table 1).

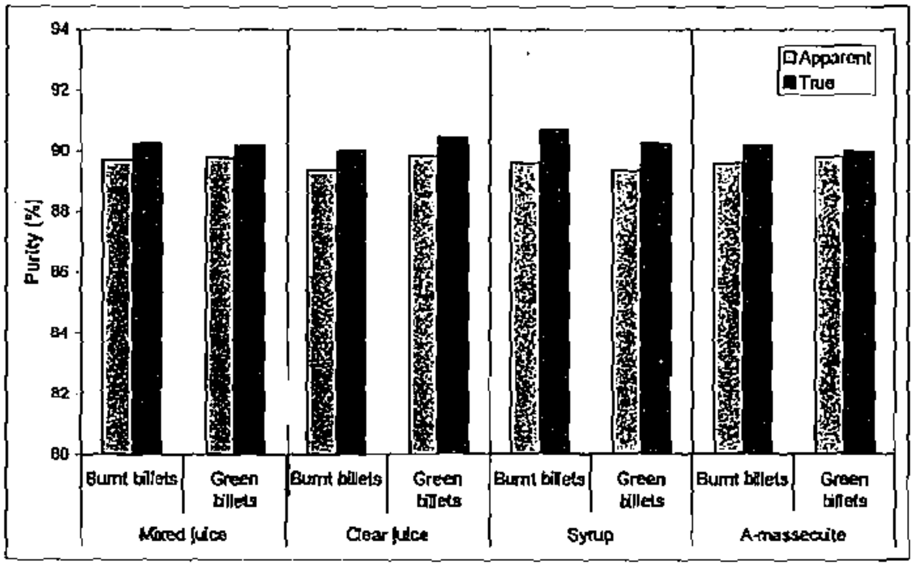

Fig. 12. Purity levels in UCL pilot plant samples

The reducing sugars (Fig. 13) throughout the pilot plant for the NB samples showed a clear trend following the order, from highest to lowest, of green billets > burnt billets > burnt whole-stalk, with a subsequential effect clearly seen as the juice was processed across the pilot plant.

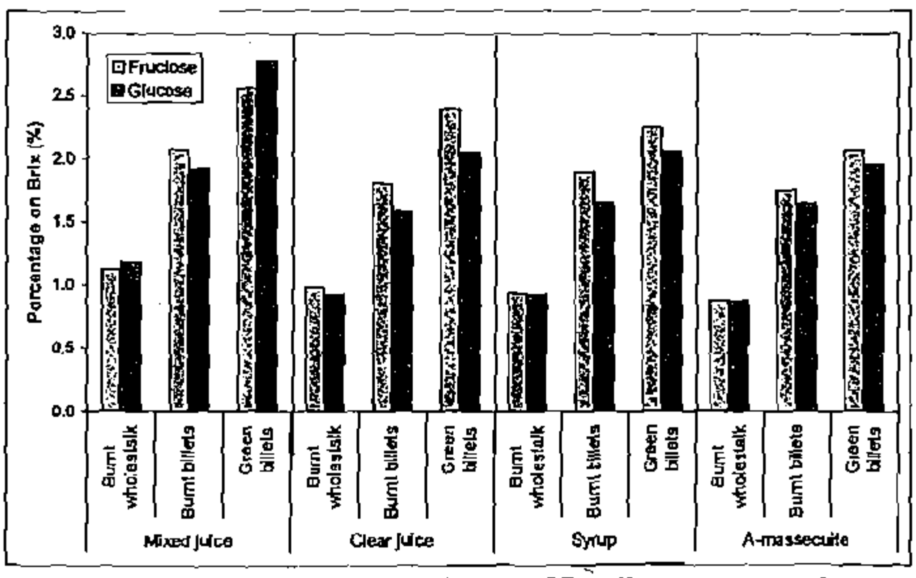

Fig. 13. Reducing sugars on Brix in NB pilot plant samples

In the UCL cane, the reducing sugars were slightly higher in the green compared to the burnt billets (Fig. 14). Since the total trash levels delivered to UCL on the 2 trial days were very similar, this effect is mostly due to the type and not the amount of trash delivered, with the green billets having higher GL and lower BL levels compared to the burnt billets (Table 1). While the total trash and GPR levels of these samples were similar for both billet types, the RS/ash ratio trend showed a clear correlation with the GL/BL ratios (Table 1). The GL/BL ratios were substantially higher in the burnt billets (2.4) compared to the green billets (0.5) (Table 1).

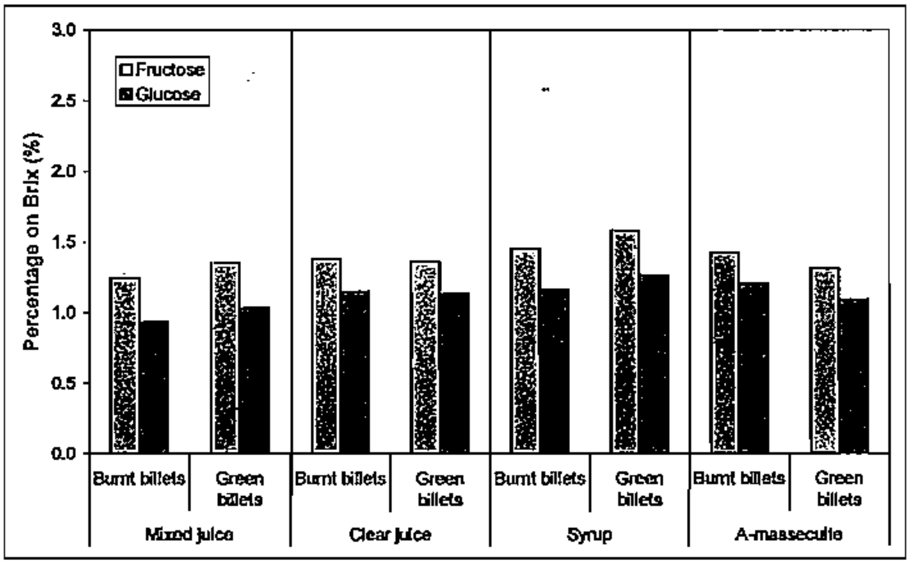

Fig. 14: Reducing sugars on Brix in UCL pilot plant samples

The NB and UCL colour results are shown in Figs. 15 and 16, respectively. Values showed the same subsequential trend as the juice was processed across the pilot plant.

Most of the colour in the factory products entered the factory with the cane, as evideneed by the MJ colour compared to the massecuite colour (Figs. 15 and 16). The burnt whole-stalk MJ had markedly lower eolour than the two billet types and generally, green billets exhibited slightly more eolour than burnt billets. Furthermore, the pattern of differences in colour for the MJ governed the differenees in the other samples formed across the process (Figs. 15 and 16).

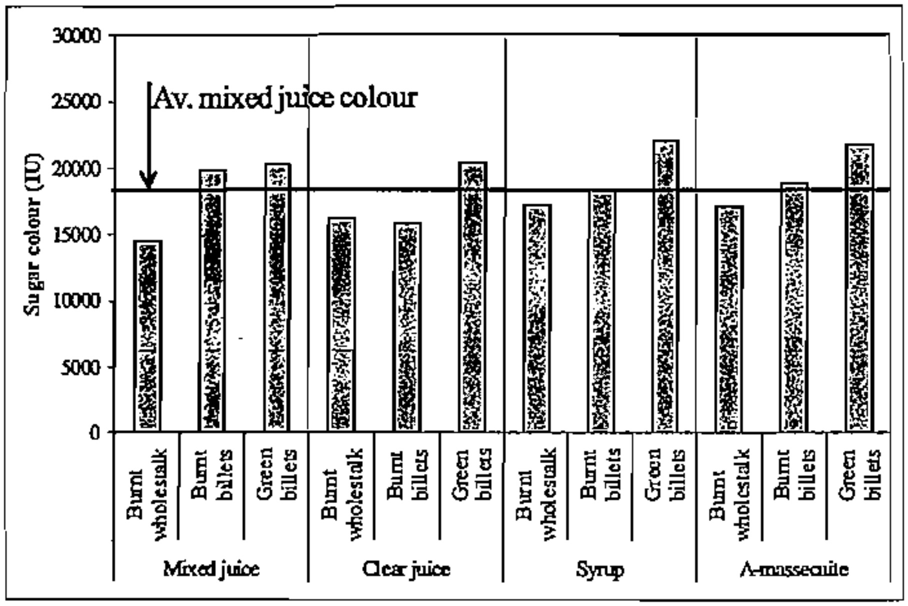

Fig. 15. Colour in NB pilot plant samples

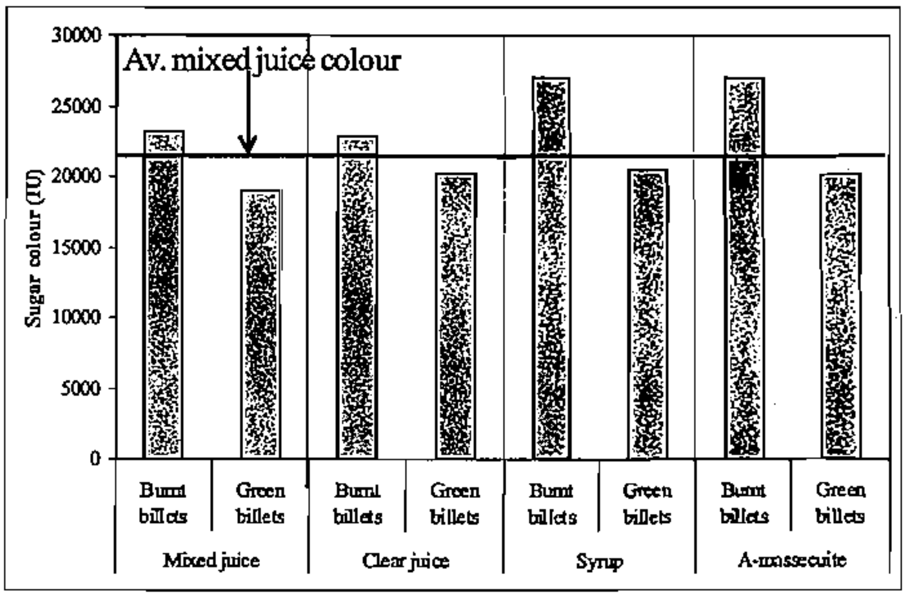

Fig. 16. Colour in UCL pilot plant samples

The drop in colour over clarification from MJ to CJ for the burnt billets indicates that the colorants particular to this harvesting method are most likely more easily removed during clarification (burnt billets contained predominantly more GL compared to green billets which contained more BL). The results further emphasize that most of the colour in the factory comes from the cane and very little, comparatively, is formed and degraded across the factory. Molasses colours (not shown) also followed the subsequential effect.

The UCL colour results in Fig. 16 were different to those for NB factory (Fig. 15). Despite a similar level of total trash between the factories, there was more colour at UCL, particularly with burnt billets. UCL operates a diffuser which is known to produce more colour, especially from GL, than tandem mills (Rein, 1995). While the total trash and GPR levels of the UCL samples were similar to the NB samples, the UCL samples had a much lower GL/BL ratio for the green billets (0.5) when compared to the burnt billets (2.4) (Table 1). The contradictory results from the two factories suggest that colour differences are likely caused by the GL/BL ratios, particularly the relative amounts of green leaves (Table 1). This is further evidenced in Table 4, which shows that GL from the N12 variety have more colour than BL. These results indicate that the type of trash, as well as the amount of trash, has a much greater effect on the colour of juice and downstream products than previously considered by the sugar industry.

Colour of Affinated Sugar

The final affinated sugar colours from NB and UCL factories are illustrated in Figs. 17 and 18, respectively. The colours of the NB A-sugars were 4920 IU for burnt whole-stalks, 8770 IU for burnt billets, and 8590 for green billets. The colours of the UCL A-sugars were 7770 IU for burnt billets and 5620 for green billets. The colours of the A-sugars and affinated sugars were measured by the ICUMSA method at pH 7.0 that is used for international trade purposes. However, it must be noted that in some countries a different colour method is used for payment, such as the Domino™ method in the USA. The Domino™ method is conducted at pH 8.3 (i.e., >7.0) so the colour units are higher than ICUMSA colours. Conversely, if a colour method is conducted at pHs <7.0 then the colour is lower.

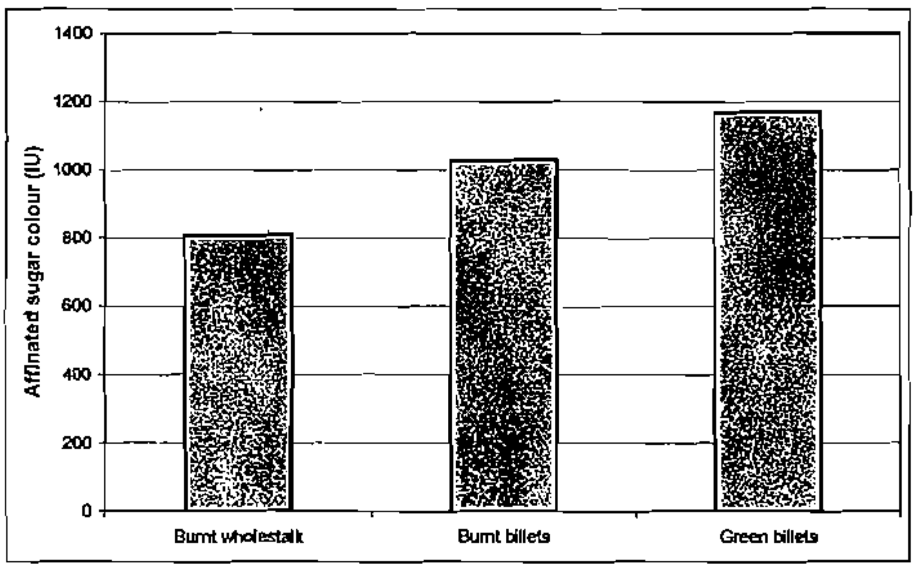

Fig. 17. Colour of NB pilot plant affinated sugar

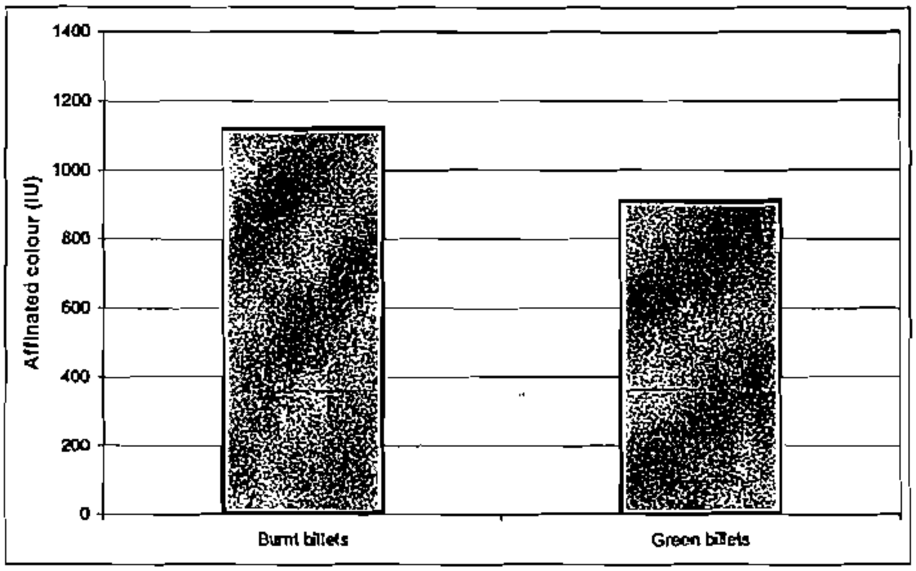

Fig. 18. Colour of UCL pilot plant affinated sugar

NB affinated sugar colours were strongly correlated (R^2=0.984) with the total trash levels indicating that increased trash caused a linear increase in colour. When NB and UCL colour were combined the correlation was R^2=0.708. On average, the colour transfer from syrup to affinated sugar was generally ~5% for all of the samples. Although this is higher than the expected 3% (syrup to VHP is 6%; VHP to affinated is 50%), it is consistent for all of the samples and subject to the specific affination procedure used in the pilot plant. Moreover, for every 1% increase in total trash levels there was an increase in the colours of affinated sugar of 25 IU (equivalent to 50 IU in VHP sugar).

Godshall (2005) reported that, by far, the largest contributors to raw sugar colour are the cane (stalk and trash) derived colourants. These are phenolic-based colourants complexed with high molecular weight (HMW) polysaccharides and processing in the factory does not substantially change the nature of these juice colourants (Godshall *et al*, 2002). Godshall (2005) reported they contribute at least 65% to the colour in affinated sugars. The HMW colourants are also preferentially found in the affinated sugar crystals (Tu, 1974).

The affinated sugars produced at NB from green billets were higher in colour than those from burnt billets (Fig. 17); however, the opposite was true for green and burnt billets at UCL, respectively (Fig. 18). The explanation for this can be seen in Table 1 which shows that the burnt billets at UCL actually contained more GL and GPR than green billets, whereas the burnt billets at NB contained less GL and GPR than green billets. This is further reinforced with strong polynomial correlations existing between %GL or %GPR with affinated sugar color (Fig. 19). In strong contrast, there was no significant relationship between %BL and affinated sugar color. Therefore, not only does the amount of trash processed at the factory affect colour of affinated sugar but also the type of trash, especially GL.

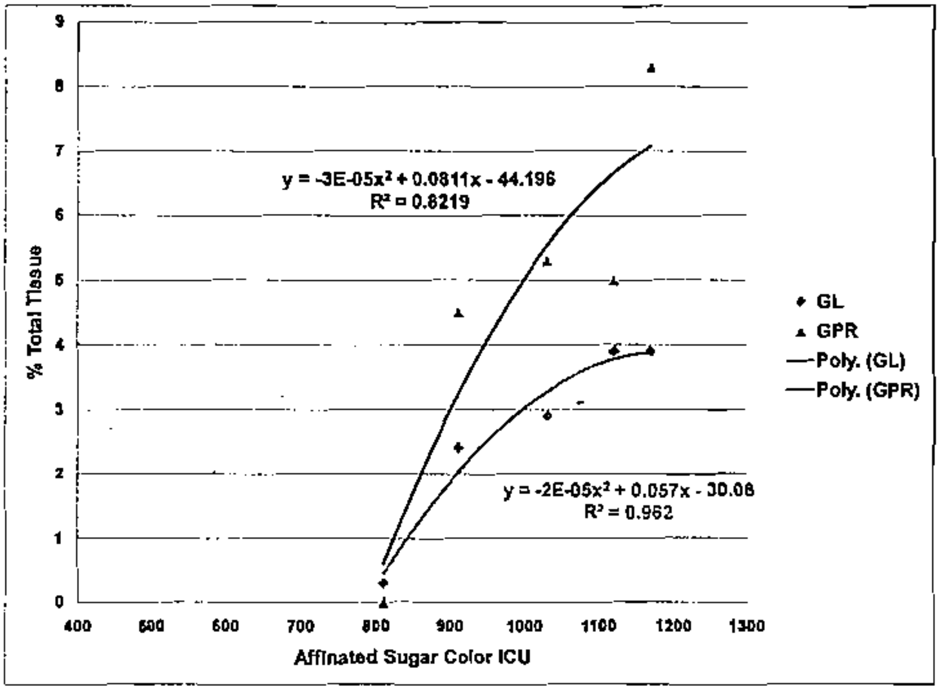

Fig. 15. Affinated sugar colour versus % GL and GPR tissues for both NB and UCL

Colour removal at the refinery is mostly perfected (Godshall, 2005) but the processes are eapital and equipment intensive. To simplify the process refiners are generally requesting that more of the colour removal work is done at the factory producing the sugar they purchase. This explains the increased world-wide production of VHP, VVHP and VLC raw sugar. Colour removal processes, generally, include improved unit processes, chemically changing the nature of the colour molecules so that they are no longer coloured or will no longer transfer to the crystal, and physical removal of colour molecules (Godshall, 2005). Improved unit processes include clarification, boiling schemes and centrifugation. Chemical processes include the use of sulfite, hydrogen peroxide, and ozone. Physical removal processes usually include adsorptive processes such as ion exchange resins, activated or powdered carbon, and bone char. However, the results presented bere strongly suggest that even a small reduction, e.g., <10% in total trash levels proeessed at the factory, could be more efficient and cost-effective than other factory colour removal processes. Moreover, slight removal of trash has additional advantages of improving purity and, therefore, sugar yields. Certainly, slight trash removal should be included in color eontrol strategies at the faetory. As only a small amount of trash removal may be needed this eould most likely be achieved by (i) a slight increase in the combine fan speed (an increase in the ground speed of the combine would run the risk of leaving more cane stalks in the field; Herman Waguespack, American Sugar Cane League, personal eommunication), (ii) slightly lowering the cutter height on the combine harvester, or (iii) using light dry cleaning at the faetory (Eggleston et al, 2009a). Furthermore, recent research using a Cameeo 3500™ combine harvester in Louisiana (Viator *et al* 2004) indieated that a high rpm speed on the primary extractor fan (1050 rpm) relative to other lower fan speeds (650 and 850 rpm) increased theoretical recoverable sugar by 10% but decreased cane tonnage by 15%. This increase in cane quality with a decrease in eane yield caused similar sugar yields for the three fan speeds. Moreover, the highest fan speed caused a US$240/ ha increase in net income compared to the lowest fan speed, when complete harvesting and shipping costs on a per area basis were analysed together. Therefore, overall, high quality cane, even without premium pay schedules, can result in *increased profits for both growers and processers*. Furthermore, growers that send high amounts of extraneous matter to the factory may be increasing their cane yield but not their profits (Viator *et al* 2004). Scandaliaris *et al* (2004) also reported higher cane quality with the new model combine harvester such as the Cameco 3500™. The Cameco 3500™ combine harvester has new design features relative to the superseded Cameco CH2500™ model, which enhance the performance of the machine to harvest green cane (Viator *et al* 2007)

<u>Rheological Properties of Syrups and A-massecuites</u>

Rheological properties were measured using an Oscillatory Deformation Rheometer (ODR). This technique is different from rotational viscometers of the Brookfield type, more commonly used in the sugar industry and provides more information about viscosity and intermolecular network associations within the sample (Eggleston and Côté, 2009). A moderate correlation ($R^2 = 0.72$) was found between dynamic viscosity (at 2.5 rad/sec) of massecuites and total % trash, indicating that the viscosities did tend to increase with increased trash levels (Muir *et al*, 2009). This warrants further investigation. The viscosity ranking at MJ did not carry through to subsequent stages, suggesting that factors other than trash levels dominated at these later stages, such as process control and operation.

MAJOR CONCLUSIONS

- Although increased total trash levels can be expected with green cane compared to burnt cane, the levels of increase and types of trash are dependent on the exact conditions and practices during harvesting. Moreover, burnt cane is more susceptible to deterioration than green cane, and billeted cane (green or burnt) is more susceptible to deterioration than whole-stalk cane (Eggleston *et al*, 2008).
- The effects of increased trash on the front end factories, *i.e.*, mill chokes, slower crushing rates, as reported by others, were confirmed. Increased trash levels resulted in decreased MJ purities in the factories. For every 1% increase in trash there was an approximate 0.4% decrease in MJ purity.
- Stalks contributed more to the load of colour delivered to the factory than the trash tissues because of their higher mass and volume. The contribution of colour from stalks to delivery of colour to the factory should, therefore, not be underestimated.
- The consistency and sizes of the floc particles in the clarifier mud changed dramatically due to the presence of more trash. An increase in trash, generally, caused a corresponding increase in the settling rate but also significantly higher mud volumes per MJ Brix unit.
- The effect of trash on processing of the mixed juice in the pilot plant was a reduction in purity all the way through to A-massecuite.
- An increase of 400 IU colour units in MJ was measured per 1% increase in total trash delivered. The green leaves have a greater impact on the colour produced at a diffuser than a tandem mill faetory.

- An increase in the colours of affinated sugar of 25 IU (equivalent to 50 IU in VHP sugar) was measured per 1% increase in total trash. Furthermore, the type of trash processed, i.e., GPR and especially GL, also markedly affected the affinated sugar colour. Slight trash removal in the field or at the factory should be included in colour control strategies at the factory.

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